

PB 176844

52



PAUL WEIR COMPANY

MINING ENGINEERS

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

A FEASIBILITY STUDY
OF THE
RECOVERY OF SULFUR AND IRON
FROM COAL PYRITES

Paul Weir Company
Chicago, Illinois

May, 1966

Table of Contents

<u>SECTION</u>	<u>Page</u>
1.0 Introduction	1.
1.1 Object and Scope of Report.	1.
1.2 Acknowledgements.	1.
2.0 Summary & Conclusions	3.
3.0 Project Analysis	5.
3.1 Pyrite as a By-Product from the Desulfurization of Coal.	5.
3.2 History of Recovering Pyrite from Coal.	7.
3.3 Sulfur Consumption and Demand.	8.
3.4 Methods for Recovering Sulfur and Iron from Pyrites.	10.
<u>Figure No. 1</u> Simplified Flow Diagram of a Sulfur Dioxide Recovery, Wet-Process, Titlestad Contact Plant.	14.
3.5 Concentration of Pyrite from Coal.	15.
<u>Table No. 1</u> Estimated Pyrite Recoverable from Cleaning Plants Described in Case Studies A through F in the Main Report (October, 1965).	17.
<u>Table No. 2</u> Theoretical Pyrite Recovery When Cleaning Various High Sulfur Pennsylvania Coal Beds Utilizing Maximum Desulfurization Coal Preparation Plans A, B and C (Exhibit A).	18.
<u>Figure No. 2</u> Coal Preparation Plant-Pyrite Beneficiation Circuit.	19.
3.6 Suggested Method for Recovering Sulfur and Iron from Coal Pyrites.	20.
<u>Figure No. 3</u> Simplified Flow Sheet of Contact Sulfuric Acid Plant Utilizing Coal Pyrites.	21.
<u>Figure No. 4</u> Suggested Flow Sheet for Magnetic Reduction of Iron Calcines from Fluidized-Bed Pyrite Roasters.	23.

Table of Contents (continued)

<u>SECTION</u>	<u>Page</u>
4.0 Economics	25.
<u>Table No. 3</u> Estimated Capital Investment for Contact Sulfuric Acid Plants Utilizing Coal Pyrites.	28.
<u>Table No. 3-A (Supplement)</u> Processing Equipment.	29.
<u>Table No. 4</u> Estimated Manufacturing Costs for Contact Sulfuric Acid Plants Utilizing Coal Pyrites Cost Per Short Ton 100% H ₂ SO ₄ .	30.
<u>Table No. 5</u> Estimated Sulfuric Acid Credits, Per Short Ton of Clean Coal from Plan A - 10,000 t.p.d. Clean Coal.	31.
<u>Table No. 6</u> Estimated Iron Calcines or Sinter Credits Per Short Ton of Clean Coal Based on 10,000 t.p.d. Clean Coal (Plan A).	32.
<u>Table No. 7</u> Summary of Acid and Iron Credits and Adjusted Cost Per Short Ton of Clean Coal Based on Production of 10,000 t.p.d. Clean Coal (Plan A).	33.
<u>Table No. 8</u> Supplementary Credits.	34.
5.0 References	35.
6.0 Supplementary References	37.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

A FEASIBILITY STUDY
OF THE
RECOVERY OF SULFUR AND IRON
FROM COAL PYRITES

SECTION 1.0 Introduction

1.1 Object and Scope of Report

Under contract to the Public Health Service, through the Division of Air Pollution of the U.S. Department of Health, Education and Welfare, the Paul Weir Company has investigated the feasibility of reducing the sulfur content of coals by generally known coal preparation methods. This work was accomplished under Contract No. PH 86-65-29, dated December 15, 1964, and a report was written and submitted in October, 1965.

On January 31, 1966, a supplemental agreement was made to continue the feasibility study (at no additional cost to the Government), in order to incorporate data developed during the course of the work, on the practicability and economics of recovering iron sulfides (pyrites) as a by-product of the desulfurization of coal by coal preparation methods.

This supplemental report contains the results of the additional data obtained with particular reference to the economic feasibility of recovering sulfur and iron from pyrites removed from coal. It discusses the beneficiation processes required to obtain the proper grade of pyrite; the methods of treating pyrite to obtain sulfur (in the form of sulfuric acid) and the processing of the iron calcines to obtain suitable grades of iron oxide.

1.2 Acknowledgements

The Paul Weir Company project engineers for this study were Mr. Raymond E. Zimmerman, Vice President and Mr. George H. Roman, Mining Engineer.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

The Paul Weir Company throughout the implementation of the Contract, has worked in close liaison with Mr. Paul W. Spaite, Deputy Chief of the Engineering R & D Section, Laboratory of Engineering and Physical Sciences, Division of Air Pollution, who is directly involved in the supervision of this Contract.

In addition to conducting an intensive literature survey, a field trip was made to the Bethlehem Steel Company's Sparrows Point pyritic roasting and sulfuric acid plant. Their cooperation is gratefully acknowledged.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

SECTION 2.0 Summary & Conclusions

- 2.1 The world-wide demand for sulfur is increasing rapidly. Long-term growth which had been growing at a rate of 4.0 percent per year now shows increases of 6.5 to 10.0 percent annually.
- 2.2 Seventy-five percent of all sulfur produced ends up in the form of sulfuric acid. Nearly 25 million tons of sulfuric acid were consumed in the United States in 1965, compared with 23 million tons in 1964. The major use of acid is in the making of fertilizer, but large quantities are consumed in steel making and in the chemical industries.
- 2.3 The price of sulfur and/or sulfuric acid has been increasing with demand. Published prices for sulfur in March, 1966, reached \$28.50 per long ton at Tampa, Florida, and higher in the northern states. The price of sulfuric acid parallels that of sulfur. Posted prices in May, 1966, were \$27.65 per long ton for 100 percent H_2SO_4 in the midwest and \$26.75 on the east coast.
- 2.4 Although over 70 percent of sulfur produced in the United States comes from the Gulf States, using the Frasch process, the potential use of pyrites is of increasing importance, and in fact, it is estimated that world-wide, 40 percent of all sulfuric acid comes from pyritic minerals.
- 2.5 Coal pyrites represent one of the largest reserves of potential sulfur in the United States. The U.S. Bureau of Mines estimates as high as 5 billion tons available from this source^{9/}.
- 2.6 In present day modern coal preparation plants treating high sulfur coals, the percent of pyrite in the plant refuse or waste material may reach as high as 28 percent with possibly an average of 15 percent. By further fine crushing of coals before preparation to minus 3/8 inch or less, pyrite content in plant refuse may reach as high as 50 percent. This refuse can be further beneficiated to produce grades of pyrite running 42 - 48 percent sulfur, with the carbon content less than 5 percent. The nature of treatment and fineness of grind will depend upon the pyrite-coal-shale grain size needed for liberation.
- 2.7 The proposed method of treatment is to utilize fluidized-bed roasters to process beneficiated coal pyrite to provide sulfur dioxide for introduction into a wet gas type contact acid plant. The residual material from the roasting is iron calcines in the form of Fe_2O_3 . The latter, if pure enough, can be sintered and sold as iron ore, depending upon the grade of coal pyrites roasted.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

Higher grade iron can be produced by further treatment of the calcines, if required.

- 2.8 Capital and operating costs have been calculated for three sizes of fluidized-bed roasting -- contact acid plants, rated at 200, 450 and 700 tons per day of sulfuric acid. Fixed capital requirements are estimated for these three plants as \$2,880,000; \$4,268,000 and \$6,090,000, respectively. Depending upon individual coal preparation plants and the degree of beneficiation required to obtain proper grade of pyrite, estimated additional costs to the coal preparation plants may vary from \$150,000 to \$200,000.
- 2.9 Estimated f.o.b. plant manufacturing costs for the acid plants are \$14.58, \$9.92 and \$8.42, respectively. Considering current market prices, the profit per ton for 100 percent sulfuric acid will range from \$4.07 to \$10.23 per ton depending upon the plant size, and assuming the only cost for the coal pyrite is the nominal cost of beneficiating preparation plant refuse.
- 2.10 Iron calcines, by-products from the pyrite roasters, may be available in amounts of 80 t.p.d. for the small plant to 280 t.p.d. for the larger plant. Calcine profits in these three plants will vary from \$4.00 to \$5.75 per short ton. It is questionable whether the smaller plant would justify a sintering operation due to the small amount of calcines produced.
- 2.11 Using Plan "A" in the text for a 1,000 ton per hour high sulfur coal preparation plant, it may be possible, depending upon plant location and size of the acid plant, to obtain combined acid and iron calcine credits of from \$0.10 to \$0.81 per ton of clean coal when producing 10,000 tons of coal per day.
- 2.12 Energy credits in the form of high pressure steam, obtained in the exothermic pyritic roasting reactors can, where such steam can be used, generate up to 235 KWH for each ton of pyrite roasted.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

SECTION 3.0 Project Analysis

3.1 Pyrite as a By-Product from the Desulfurization of Coal

As mentioned in the main report (October, 1965) on the desulfurization of coal by known methods of coal preparation, sulfur occurs in coal in three forms. It is present as an organic part of the coal substance, as iron sulfide and as sulfates.

The chief forms are organic and iron sulfides. Sulfates, mainly calcium and iron, rarely exceed more than a few hundredths percent. Organic sulfur is an inherent part of the coal substance itself and cannot be removed physically from the coal without changing the nature of coal to a liquid or gaseous state.

Iron sulfides, FeS_2 , generally called pyrites may be either marcasite or pyrite, depending upon crystal structure. The chemical formula is the same in either case.

The organic sulfur cannot be removed by coal preparation or beneficiation methods. Therefore, the desulfurization of coals can only be accomplished by removing the pyritic forms (marcasite is included as pyrite).

The extent to which pyrite can be removed from coal depends upon how finely disseminated the particles are mixed within the coal and the extent of processing to remove the pyrite.

As stated in the main report of October, 1965, all coal will require some prior crushing before treatment to liberate pyrite and many high sulfur coals will require pulverization to at least 14 mesh or even to 30 mesh or finer for effective separation.

This finer crushing enhances the possibility of obtaining purer pyrite although it is possible to obtain suitable grades of pyrite from some relatively coarse coals. Generally speaking, to get proper liberation to obtain lower sulfur coals, and conversely, pyrite particles free of carbonaceous and other mineral matter, finer crushing will generally be required.

Coal preparation plants are designed to remove non-carbonaceous material from the coal (to varying degrees). This material, called plant refuse or reject, is largely made up of various types of material such as shale, sandstone, clayey matter, pyrite and varying amounts of laminated coal-shale particles and bony coal (high inherent ash coal).

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

The amount of a plant reject may vary from as little as 5 percent of the feed to the plant, or for very dirty coals, as high as 40 percent. A possible average for most American plants is about 20 percent, and 25 percent is not uncommon.

The sulfur content of these plant rejects or refuse will vary widely, depending upon the amount of pyrite originally in the coal, pyritic liberation in the processing, and the quantity of the other extraneous impurities in this waste material.

Except for carbonaceous material which may have some organic (and sulfate) sulfur, the bulk of the sulfur in plant refuse is pyritic. This may be 75 percent of all the refuse sulfur or as much as 90 to even 100 percent.

Total sulfur in present day plant refuse from high sulfur coals (coals over 2.0 percent sulfur) will vary from possibly as low as 4.0 percent to as high as 25.0 percent. On a pyritic basis this could be 8 to 40 percent FeS_2 .

Obviously, to become economically useful, the plant refuse would generally have to be re-treated to be concentrated to a proper grade, although in some plants this can be done by merely cutting out part of the refuse stream where the pyritic sulfur is already at a high level.

Even relatively rich coal pyrite concentrates contain some impurities, depending upon the degree of concentration and particle size required for liberation of pure FeS_2 .

Lump pyrite obtained from the Pittsburgh, Sewickley and Redstone beds in northern West Virginia have the following analysis, as reported by S. P. Burke and R. Downs ¹:

<u>% Sulfur</u>	<u>% Iron</u>	<u>% Bituminous Matter</u>	<u>% Silica</u>
50.54	41.85	7.52	0.385

A pyrite concentrate from refuse obtained at a western Pennsylvania coal preparation plant cleaning Pittsburgh bed coal, as reported by D. R. Mitchell²:

	Total Sulfur	43.36
	Iron	37.44
	Total Carbon	8.83
	Silica (SiO_2)	2.51
	Alumina (Al_2O_3)	4.97
	Magnesium Oxide (MgO)	0.51
	Hydrogen	0.73
	Lime (CaO)	0.68
Arsenic	- 0.12	
Phosphorus	- 0.05	
Undetermined	- 0.80	

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

Pyrite concentrate obtained from a special treatment plant of the Pittsburgh and Midway Coal Mining Company located in Kansas, as reported by K. A. Spencer^{3/}:

Sulfur	45.38 %
Iron	40.90
Total Carbon	4.12
Sulfate Sulfur	0.23
Moisture	3.80
Silica (SiO ₂)	0.27
Lime (CaO)	2.40
Copper	0.52
Arsenic	0.004
Zinc	0.19
Lead	0.17
Insoluble	1.54
Undetermined	0.476

H. F. Yancey^{4/} reports on the amount of carbon content of coal-pyrite concentrates, using a jig to concentrate the pyrite:

Material	% Total Sulfur	% Total Carbon	% Organic Carbon
First Bed Concentrates	44.77	2.90	2.27
Pyrite Lump Concentrates	45.88	2.60	1.83
First Hutch Pyrite Concentrates	45.03	3.75	2.96
Recleaned Pyrite Middlings	43.88	6.76	6.61

As a rule, specifications for pyrite concentrates to be sold to merchant sulfuric acid plants state a maximum allowable range of 5 to 8 percent for the carbon limit and a 42 to 45 percent minimum sulfur limit. Where flash roasting is practiced, the pyrite is usually finer than 100 mesh. Twenty mesh size is satisfactory for some users.

Aside from carbon, the chief deleterious substance in pyrite may be arsenic. This latter constituent as well as other metals is very small in pyrite associated with coal. Higher carbon content could be tolerated if the plant was designed specifically to process coal pyrites.

3.2 History of Recovering Pyrite from Coal

The recovery of pyrite from coal has had a "checkered career" in the United States, not due to technical problems, but to economics. Interest in the past occurred during the war years. In both World War

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

I and II, when there was critical danger of insufficient supplies of pyrite and sulfur, some plants were erected and pyrite produced and shipped to sulfuric acid plants. 2,3,4,5,6,7/

During World War I shipments of hand-picked pyrite were made from a number of coal mines in Illinois, Indiana, Western Kentucky, Ohio and Pennsylvania. A concentrating plant was erected for separating pyrite from picking table refuse at Danville, Illinois, and a smaller plant was built at Gillespie, Illinois, in 1918. The Consolidation Coal Company at Fairmont, West Virginia, operated a sulfuric acid plant using pyrite from coal during this time.

In World War II, the Midland Electric Coal Corporation shipped 12,000 long tons of pyrite containing 46 percent sulfur from its Atkinson preparation plant. The Snow Hill Coal Corporation in Indiana produced pyrite from its Talleydale plant.

The Mineral Products Company, a subsidiary of the Pittsburgh and Midway Coal Mining Company designed and operated a plant for the recovery of pyrite. This plant was operated for a number of years, but was forced to close down due to the competition of the normal sources of sulfur 3/.

These plants produced pyrite concentrates which generally had to be shipped by rail, and at an average f.o.b. value of about \$3.00 per long ton, was a losing proposition. Their situation, however, could have been improved if they produced sulfuric acid instead of only pyrite concentrates. As will be discussed, this will involve the proper capacity of plants as well as nearness to market and sulfur demand.

3.3 Sulfur Consumption and Demand

The situation when sulfur was in oversupply has disappeared. World-wide emphasis on fertilizer production as well as increased industrialization in all parts of the world has completely changed the picture 8,9/. The long-term growth in sulfur consumption which historically approached 4 percent a year, gave way under the pressure of recent annual increases of the order of 6.5 percent (1963), 10.0 percent (1964) and 8.3 percent (1965), to much higher rates.

There are no indications that this demand will decrease for many years ahead. It has been estimated that in 1970, the free world will need an additional seven million tons of sulfur over and above the 22.5 million tons produced in 1965 8/.

The annual production of sulfur in all forms in the United States was 6.6 million long tons in 1963, valued at \$125 million 9/. In this

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

year, 74 percent was produced by the Frasch process in Texas and Louisiana, and the rest from sour natural gas and from metal sulfides. The metal sulfides are usually pyrites.

Pyrites provided 40 percent of all sulfur produced in the world in 1963, and although often mined as pyrite, as in Spain, Portugal, Italy and Japan, in the United States they come chiefly as a by-product from metalliferous mining of copper and other ores.

Reserves of native sulfur recoverable by the Frasch process are estimated as from 50 to 200 million tons; surface deposits at 30 million and sulfides, other than in coal, from 100 to 150 million tons.

Sulfur in coal is considered to be the second largest reserve. Coal in minable deposits may contain as much as 5 billion tons of sulfur ⁹/₁₀.

The price for sulfur has been increasing with demand. Published prices in January, 1965, were \$27.50 per long ton, f.o.b. gulf ports and \$25.50 f.o.b. mines. Dark sulfur used for making acid is generally a dollar less. In March, 1966, prices quoted for sulfur had reached \$28.50 per ton at Tampa, Florida, and higher in the northern states. These domestic prices are substantially lower than overseas markets where the differential may be as much as \$10 per ton.

The price for sulfuric acid parallels that of sulfur. The Wall Street Journal in May, 1966, quoting DuPont, Olin and Stauffer Chemical companies posted prices of \$27.65 per ton for 100 percent acid in the midwest and \$26.75 per ton for the east coast. West coast prices were \$29.55 at the same time. These prices have been rising steadily over the past few years.

Nearly 25 million tons of sulfuric acid were consumed in the United States last year, compared with 23 million in 1964. The major use of acid is in making fertilizer, but large quantities are consumed in steel making, production of dyes and other chemicals as well as insecticides.

Sulfuric acid in most steel plants is used for pickling of sheet, plate, rod and wire, and for the recovery of ammonia at coke ovens. A good example is in the Sparrows Point plant of the Bethlehem Steel Company where with an annual rated capacity of 6,200,000 ingot tons of steel, 10,000 tons of sulfuric acid are used per month 10,18.

Although one generally considers the treatment of pyrite primarily for its sulfur content, the resultant product after the removal of the sulfur is iron. This iron can be recovered for use as an iron oxide concentrate. Except under certain economic conditions, however,

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO 6, ILLINOIS

the tonnages involved would generally not be attractive in the United States.

High grade iron ore costs around \$10.80 per long ton. The economics of its recovery for a coal pyrite sulfuric acid plant would be doubtful except in special relationship with the steel companies and where freight costs are minimum.

An example of its use is at the Sparrows Point plant of Bethlehem Steel. In many other countries the calcines or pyritic cinders are a valuable source of iron for blast furnaces and direct reduction processes.

3.4 Methods for Recovering Sulfur and Iron from Pyrites

The roasting of pyrites can be studied from several points of view. First, the ore may be mined or collected specifically for its sulfur and iron derivatives. Also, pyritic concentrates may be obtained as a by-product from the mining of non-ferrous metals, such as copper or zinc. In the latter case, systems are usually designed primarily to extract the non-ferrous values from the pyrite concentrates along with the sulfur and iron derivatives, and apply primarily to metal mining operations.

Pure pyrite, FeS_2 , runs 53.42 percent sulfur and 46.58 percent iron. The primary chemical reactions that are of major importance in the roasting of pyrites are 10,11:

- (1) $4\text{FeS}_2 + 11\text{O}_2 = 2\text{Fe}_2\text{O}_3 + 8\text{SO}_2 + 2,995 \text{ Btu/lb. of FeS}_2$
- (2) $3\text{Fe}_2\text{O}_3 + \text{CO} = 2\text{Fe}_3\text{O}_4 + \text{CO}_2$
- (3) $3\text{Fe}_2\text{O}_3 + \text{H}_2 = 3\text{Fe}_2\text{O}_4 + \text{H}_2\text{O}$

Reaction (1) represents the roasting of the iron sulfide pyrite, in air, to remove sulfur as sulfur dioxide gas. Under proper conditions this exothermic reaction is autogenous and requires no additional fuel other than the pyrite itself. This reaction also produces the iron calcine, hematite, which can be further reduced by magnetic conversion to magnetite as indicated by reactions (2) and (3).

These reactions play a major role in pyritic roasting, are the basis for processes discussed, and clearly indicate the primary end products of pyritic roasting: sulfur dioxide gas, heat and iron oxides.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

The sulfur dioxide gases liberated during the roasting of pyrites are utilized in the production of sulfuric acid. The iron-bearing calcines which are by-products of the roasting process can be converted to artificial magnetic iron oxides. These oxides can then be concentrated, if necessary, by wet and dry magnetic separation, ground to remove gangue materials and pelletized or sintered to produce high grade magnetic concentrates suitable as blast furnace feed. In other methods, the iron calcines can be converted by direct reduction methods to high purity sponge iron which can be used as feed for electric pig iron furnaces or similar processes.

When roasted, 1,000 short tons of pyrite ore will yield approximately 11,000,000 cubic feet of sulfur dioxide gas; 235,000 KWH of generated heat and 500 tons of high grade iron calcines. This amount of sulfur dioxide gas can be used to manufacture 1,000 to 1,500 tons of sulfuric acid based on a pyritic feed with a sulfur content from 42 to 48 percent.

The primary objective in the application of any pyrite roasting system is to provide a steady flow of sulfur dioxide gas in sufficient concentration to support an acid making system. While the major source of sulfur dioxide gas for acid production in the United States has been from elemental sulfur and brimstone burners, other countries have had to rely on sulfide bearing minerals to support their acid making operations. Consequently, the development of pyrite roasters and burners have been pioneered in European and other countries.

One of the early roasters developed was the lump burner, which is still used in a few European locations ^{11/}. The lump burner consisted simply of a battery of individual ovens which required hand stoking and much attention.

With the exception of the limited application of rotary kilns in Germany, the next system of importance in roasting pyrites was the multiple-hearth or shaft type roasters developed in Europe and Australia. The multiple-hearth furnace consists principally of superimposed circular hearths enclosed in a refractory lined steel shell.

Revolving rabble arms or plows advance and mix the pyrite, which is introduced through the top of the furnace. The ore is advanced by this process until it drops successively through each hearth discharging the residual calcine through the bottom of the furnace.

Multiple-hearth roasters are in successful operation in many locations in Australia and Canada, a good example being the system utilized by the Hudson Bay Mining and Smelting Company in roasting zinc sulfides at Flin Flon, Manitoba ^{12/}.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

Continued development in pyrite roasting resulted in the flash roasting or suspension type roaster such as used by the Consolidated Mining and Smelting Company at Trail, British Columbia ^{13/}. This design utilizes the rabbling principle of the multiple-hearth roaster for drying and advancing the wet feed to a combustion chamber where the dried feed is oxidized while suspended in air. This system allows the rapid and efficient roasting of fine pyrite feed with high capacity and relatively lower capital investment as compared to multiple-hearth systems.

The development of fluidized-bed roasting marks a distinct departure from conventional pyrite roasting systems and was pioneered by the Dorr-Oliver, Inc., of Stamford, Connecticut, and the Badische Anilin & SodaFabrik (BASF) of Ludwigshafen am Rhein, Germany ^{11,14/}. The fluidized-bed roasting of pyrites involves the suspension of solid particles in an upward-rising stream of gas resulting in a fluidized mass which behaves in a manner similar to water. Intense gas to solids contact provides very efficient transfer of heat and stimulates extremely rapid and uniform chemical reactions, therefore, allowing excellent control of roasting temperatures.

The system is composed of a cylindrical reactor with feed and gas inlets and calcine and exhaust gas outlets. In operation, fine pyrite feed is introduced as a slurry containing approximately 75 percent solids at 2.4 specific gravity. The contained water is utilized to control the heat reaction thus controlling the temperature of the fluidized bed. Additional cooling water can be directly introduced into the reactor as needed and provides additional control to the system.

The introduction and development of the fluidized-bed type roaster has played an important part in the success of today's pyrite roasting system. Due to its flexibility, several applications of fluo-solid roasting systems have been developed which have encouraged many companies to consider processing pyrite concentrates previously discarded in their operations. Depending on the desired results, fluo-solid reactors may be utilized to dead roast or partial roast pyrites ^{11,14/}.

The dead roasting of pyrite is accomplished in fluosolid reactors by introducing an excess amount of air into the system thus allowing maximum sulfur yield as SO₂ gas and energy in the form of high pressure steam; this method being ideal where large amounts of acid-making materials are required. Dead roasting allows substantially complete oxidation of the sulfides with low excess air requirements. The resulting iron-bearing calcines may be sintered or sent directly to magnetic roasting systems which also utilize fluosolid reactors for the conversion to high grade magnetic iron oxides.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

One such operation, which is of interest in this category, is the Montecatini pyrite plant at Follancia, Italy 15,16,17/. This highly successful commercial operation utilizes fluosolid reactors in the dead roasting of pyrites and magnetic roasting of the iron-bearing calcines. Magnetic separation and pelletizing systems are utilized to produce high grade iron concentrates, and catalytic oxidation is used to produce sulfuric acid.

Twenty-two hundred metric tons of crude pyrite ore are processed daily at Montecatini to produce 2,200 metric tons of H_2SO_4 ; 570,000 KWH per day of electric power, and 1,100 metric tons of high grade pellets with an iron content of 66 percent.

If non-ferrous metals are present in the pyrite concentrates, as is the case at Bethlehem Steel's Sparrows Point plant, it may be desirable to retain a portion of the sulfur content in the calcines to facilitate further treatment to extract these metals 18/. This can be realized through the application of a partial roast which can be accomplished in the fluosolid reactor by supplying less than theoretical air requirements during the roasting operation.

This technique results in lower sulfur dioxide yields and concentrations that would be undesirable when roasting coal pyrites.

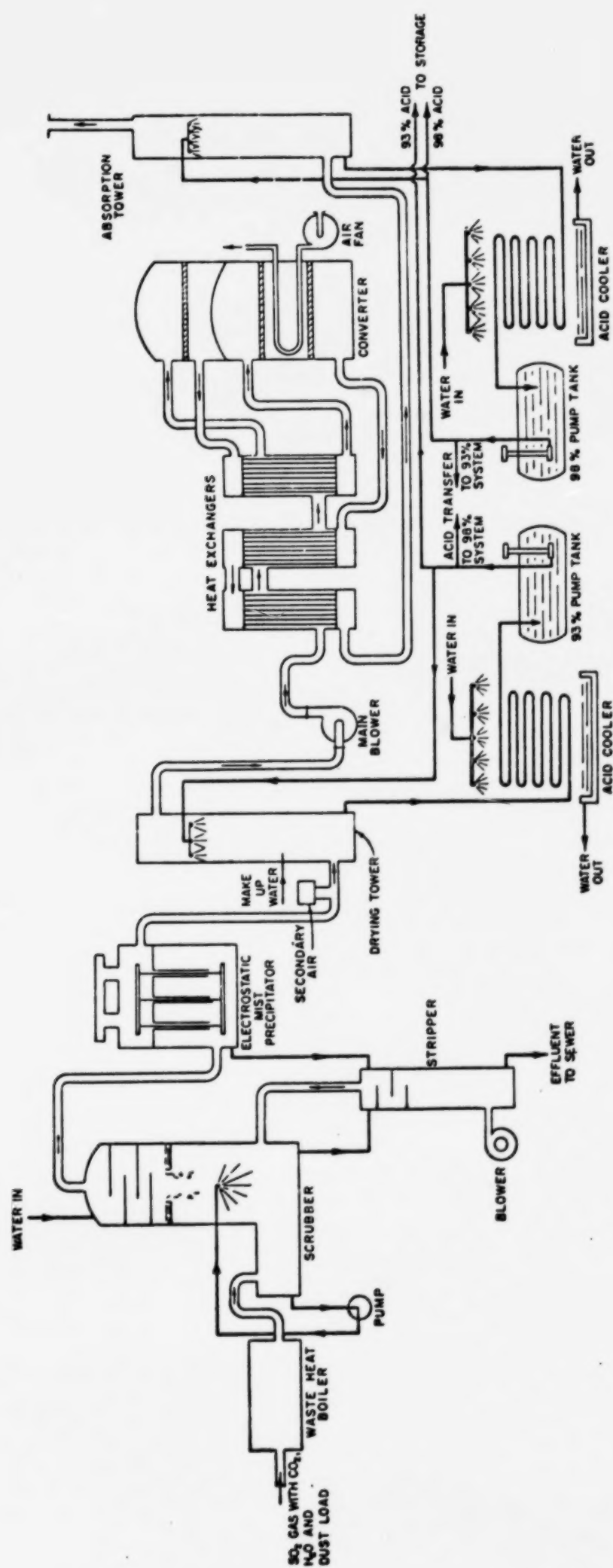
Therefore, it would appear that a dead roasting fluidized-bed system with maximum sulfur dioxide yield would be ideal for roasting coal pyrites.

Sulfur dioxide gas is converted to sulfuric acid by the chamber process and the contact process 11/. Due to the complicated reactions involved, the chamber process is losing ground in this country while the contact process has been gaining considerable favor.

In the contact process sulfur dioxide is converted by catalytic oxidation with a catalyst such as vanadium pentoxide to sulfur trioxide. The sulfur trioxide is then converted to sulfuric acid by direct absorption in concentrated sulfuric acid.

Contact acid plants are broken down into two basic types: namely, those that utilize dry sulfur dioxide gas obtained from burning elemental sulfur, and those that utilize wet sulfur dioxide obtained from roasting or burning pyrites.

Due to moisture, carbon dioxide, dust and other contaminants that are present in sulfur dioxide obtained from roasting pyrites, extensive dust collection and gas purification methods must be applied to produce a gas product suitable for acid production. This is accomplished by using waste heat boilers, high temperature cyclones, scrubbers, electrostatic mist precipitators and drying towers. A simplified flow diagram of a sulfur dioxide recovery wet process, is illustrated in Figure No. 1.



Simplified flow diagram of a sulfur dioxide recovery, wet-process, Titlestad contact plant.

Figure 1

Figure 1

Reference: Thompson, R.B. and Jukkola, W.W., "Manufacture of Sulfuric Acid".
ACS Monograph No. 144, Reinhold Publishing Corp., 1959.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

Resulting grades of sulfuric acid products from this process are 98 - 100 percent H_2SO_4 , and 66 degree Baume (93.19 percent H_2SO_4) and 60 degree Baume (77.67 percent H_2SO_4). Also with auxiliary equipment, various grades of oleum (fuming sulfuric acid) and liquid sulfur trioxide may be produced and such products may be warranted where markets exist.

In wet gas plants the overall production of sulfuric acid is generally less efficient than the conventional sulfur burning dry process plants. This is because ore roasting and sulfur dioxide producing equipment do not convert all the sulfur in the raw materials. This is also due to the loss of sulfur bearing products in waste effluents from the scrubbing and cooling equipment. Sulfur dioxide gas produced from roasting coal pyrites can be furnished in amounts to produce from 1 to 1-1/2 tons of sulfuric acid per ton of pyrite feed to this type of system when utilizing fluidized-bed roasters based upon sulfur contents of 42 to 48 percent.

3.5 Concentration of Pyrite from Coal

The main report of October, 1965 discussed by various case studies the present methods of removing pyrite in modern coal preparation plants. It also advanced several schemes for obtaining maximum sulfur reduction using a combination of crushing or pulverization and the latest techniques of beneficiation.

In existing plants the plant refuse may be the results of using jigs, Deister tables, heavy media processes, cyclones and possibly froth flotation. The coal treated is seldom crushed finer than minus 1-1/2 inches and may be as coarse as 5 to 7 inches. The difficulty of making substantial reduction of sulfur in treating coal of these sizes has been previously discussed. It is felt that to effectively reduce the sulfur content of most high sulfur coals, finer crushing must be given to the coal before beneficiation.

The several schemes for doing this, advanced in the October report, are added to this supplement in flow sheet form as Exhibit "A", being a copy of Figure No. 43 of that report.

The pyritic content from these schemes or from existing plant circuits may be widely variable depending upon the coal's original pyritic content, the purity of the pyrite, and the quantity of other impurities in the coal. There are some existing plants today where a concentrate of 40 percent FeS_2 can be obtained as a direct cut from the refuse circuit. This may be true particularly in Deister table practice where the pyrites have a sharp tendency to separate from other table refuse.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

As a general practice, however, it will be necessary to further treat coal preparation plant refuse to obtain a concentrate of pyrite sufficiently pure for roasting and use in sulfuric acid plants. One of the limiting factors is the amount of carbon permissible which in most plants is required to be not over 8 percent and preferably much less.

To remove this carbon (in the form of coal) would generally require the pulverization of the high pyritic refuse to such a size as to liberate pyrite from coal adherence. This very probably would require crushing to at least 14 mesh and possibly to 30 mesh or finer. This degree of grinding, and for that matter, the amount of beneficiation will depend upon local characteristics of preparation plant refuse.

Table No. 1 shows the theoretical pyrite yield from actual plant refuse (Case Studies A through F, October report). They are of total refuse with maximum crushing limited to 7 inches to 1-1/2 inches.

In the refuse from these studies, refuse sulfur content varies from 4.8 to 14.3 percent. Assuming 90 percent of the sulfur as coming from pyrite, the pyritic sulfur reaches as high as 28.6 percent. A proper grade of pyrite concentrate could be obtained from any of these cases by retreatment of the refuse.

Table No. 2 shows a similar table as a result of the crushing of various high sulfur Pennsylvania coals to minus 3/8 inch and minus 14 mesh. This table is modified from Table No. 7 in the main report and the basic analyses were obtained as a result of float and sink tests.

This table indicates that many Pennsylvania Appalachian coals are amenable to considerable sulfur reduction after crushing to 3/8 inch or less, that sulfur in refuse may be 8.2 to as high as 25.6 percent, and pyrite from 16.4 to as high as 51.2 percent, depending upon fineness of grind and specific gravity of separation.

Retreating the refuse could easily bring pyrite concentrate grade to acceptable limits. Assuming 90 percent of the sulfur in the refuse is pyritic and based upon a 90 percent recovery of the pyrite, a 1,000 t.p.h. coal preparation plant on these Appalachian coals should produce anywhere from 17.4 to as high as 77.9 short tons per hour of concentrated pyrite.

Figure No. 2 shows suggested methods of retreatment of high pyritic content refuse. Where the coal has been treated by Schemes A, B or C, as shown on Exhibit "A", and high sulfur reject is collected by two stage hydrocyclones after pulverizing to minus 30 mesh, a final pyritic concentrate can be prepared by directly treating on Deister tables.

Table 1

Estimated Pyrite Recoverable from Cleaning Plants Described in

Case Studies A through F in the Main Report (October, 1965)

Mine	Coal Bed	County	Crushed to	Separation Sp. Gr.	Sulfur Percent		Yield %	Refuse %	Sulfur in Refuse %	Pyrite in Refuse %	Recoverable Pyrite t.p.h.
					Raw Coal	Clean Coal					
A	Illinois No. 6	Franklin	3-1/2 x 0	1.60	2.93	2.43	91.1	8.9	8.1	16.2	13.0
B	Illinois No. 6	Montgomery	1-1/2 x 0	1.35	2.93	2.20	72.2	27.8	4.8	9.6	24.0
C	Illinois No. 5	Fulton	1-1/2 x 0	1.60	4.78	3.93	81.5	18.5	8.5	17.0	28.3
D	West Kentucky No. 9	Union	5 x 0	1.60	4.78	3.58	63.1	36.9	6.8	13.6	45.2
E	Pittsburgh	Greene	4 x 0	1.35	5.49	4.28	86.9	13.6	13.0	26.0	31.9
F	Ohio No. 8	Harrison	7 x 0	1.60	3.62	3.62	63.2	36.8	8.6	17.2	57.0
					4.07	3.10	90.0	10.0	12.8	25.6	23.0
					4.07	2.44	58.4	41.6	6.3	12.6	47.2
					2.66	2.03	94.9	5.1	14.3	28.6	13.1
					2.66	1.64	79.9	20.1	6.7	13.4	24.3
					3.55	2.62	86.6	13.4	9.6	19.2	23.1
					3.55	1.94	60.0	40.0	6.0	12.0	43.2

Notes: (1) Recoverable pyrite calculated on 1,000 t.p.h. R.O.M. feed basis, assuming that 90 % of liberated sulfur is in pyritic form containing 45 % sulfur and that 90 % of liberated pyrite is recoverable.

(2) Data for sized products indicated. If plants were designed to crush to -3/8" product, more pyrite would be liberated. Also, suitable equipment would be necessary to collect the liberated pyrite.

Table 2

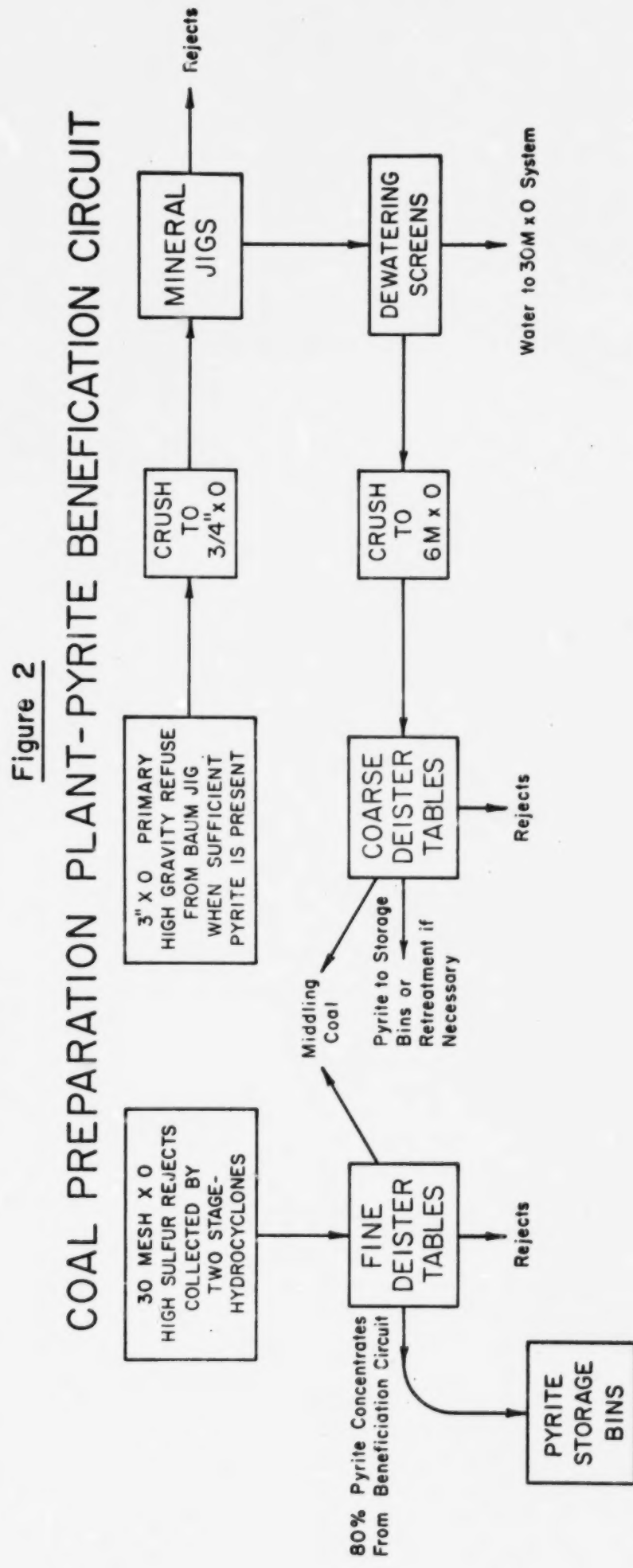
Theoretical Pyrite Recovery When Cleaning Various High Sulfur Pennsylvania Coal Beds

Utilizing Maximum Desulfurization Coal Preparation Plans A, B and C (Exhibit A)

Coal Bed	County	Crushed to	Separation Sp. Gr.	Sulfur Percent Raw Coal	Sulfur Percent Clean Coal	Yield %	Refuse %	Sulfur in Refuse %	Pyrite in Refuse %	Recoverable Pyrite t. p. h.
Upper Kittanning	Cambria	-3/8" -14M	1.60 1.60	3.76 3.76	1.27 0.90	87.2 87.7	12.8 12.3	20.7 24.2	41.4 48.2	47.7 53.3
Lower Kittanning	Cambria	-3/8" -14M	1.60 1.60	3.38 3.38	0.93 0.82	76.0 77.7	24.0 22.3	11.1 12.3	22.1 24.6	47.7 49.4
Middle Kittanning	Butler	-3/8" -14M	1.48 -	5.64 -	1.57 -	83.1 -	16.9 -	25.6 -	51.2 -	77.9 -
Upper Freeport	Indiana	-3/8" -14M	1.50 1.50	2.62 2.62	1.23 1.03	80.2 79.2	19.8 20.8	8.2 8.7	16.4 17.4	29.2 32.6
Lower Freeport	Armstrong	-3/8" -14M	1.46 1.46	2.64 2.64	1.44 1.15	90.2 92.6	9.8 7.4	13.7 21.2	27.4 43.4	24.2 29.0
Lower Freeport	Cambria	-3/8" -14M	1.50 1.50	3.29 3.29	1.61 1.34	74.9 75.1	25.1 24.9	8.7 9.2	17.4 18.4	39.3 41.2
Brookville	Clearfield	-3/8" -14M	1.55 1.55	5.00 5.00	2.19 1.76	59.7 58.7	40.3 41.3	9.2 9.6	18.4 19.2	66.7 74.1
Clarion	Jefferson	-3/8" -14M	1.45 1.45	4.57 4.57	2.01 1.81	85.3 85.4	14.7 14.6	19.4 20.7	38.8 41.4	51.3 54.4
Pittsburgh	Greene	-3/8" -14M	1.47 1.47	2.27 2.27	1.42 1.35	91.2 90.0	8.8 10.0	11.0 10.5	22.0 21.0	17.4 18.9

Notes: (1) Assuming R.O.M. Feed = 1,000 t.p.h.; 90 % of sulfur liberated is in pyritic form containing 45 % sulfur and that 90 % of liberated pyrite is recoverable.

(2) Basic data is obtained from: "The Preparation Characteristics of Bituminous Coal Reserves in Pennsylvania with Special Emphasis on Sulfur Reduction," No. SR-35, Oct. 1962, College of Mineral Industries, The Pennsylvania State University.



PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

Where the coal is crushed only to 3 inches x 0 as from a Baum jig, a high sulfur refuse can be processed to proper pyritic grade by crushing to 3/4 inches x 0, passed into mineral jigs for removal of larger extraneous matter, crushed to possibly 6 mesh and the pyrite separated on coarse Deister tables.

The nature of treatment and fineness of grind will depend upon the nature of the pyrite-coal shale mixture. The cost of concentrating pyrite from coal preparation plant refuse will likewise depend upon these conditions. It is estimated that these costs will vary from 20 cents to 50 cents per ton of pyrite concentrate containing 42 to 48 percent sulfur.

3.6 Suggested Method for Recovering Sulfur and Iron from Coal Pyrites

It is proposed to utilize fluidized-bed roasters to process the beneficiated coal pyrites to provide sulfur dioxide for introduction into a wet gas type contact acid plant. A suggested flow sheet for this scheme is illustrated by Figure No. 3 and is based on a pyrite feed ranging from 170 to 550 tons per day. This quantity of feed will supply sulfur dioxide in concentrations of 10 to 14 percent and in sufficient amounts to support an acid plant with a capacity to produce 200 to 700 tons per day of 98 to 100 percent sulfuric acid. By-products of this scheme will be 80 to 280 tons per day of iron calcines suitable for sintering or magnetic reduction, and 40,000 to 130,000 KWH per day of power through steam generation.

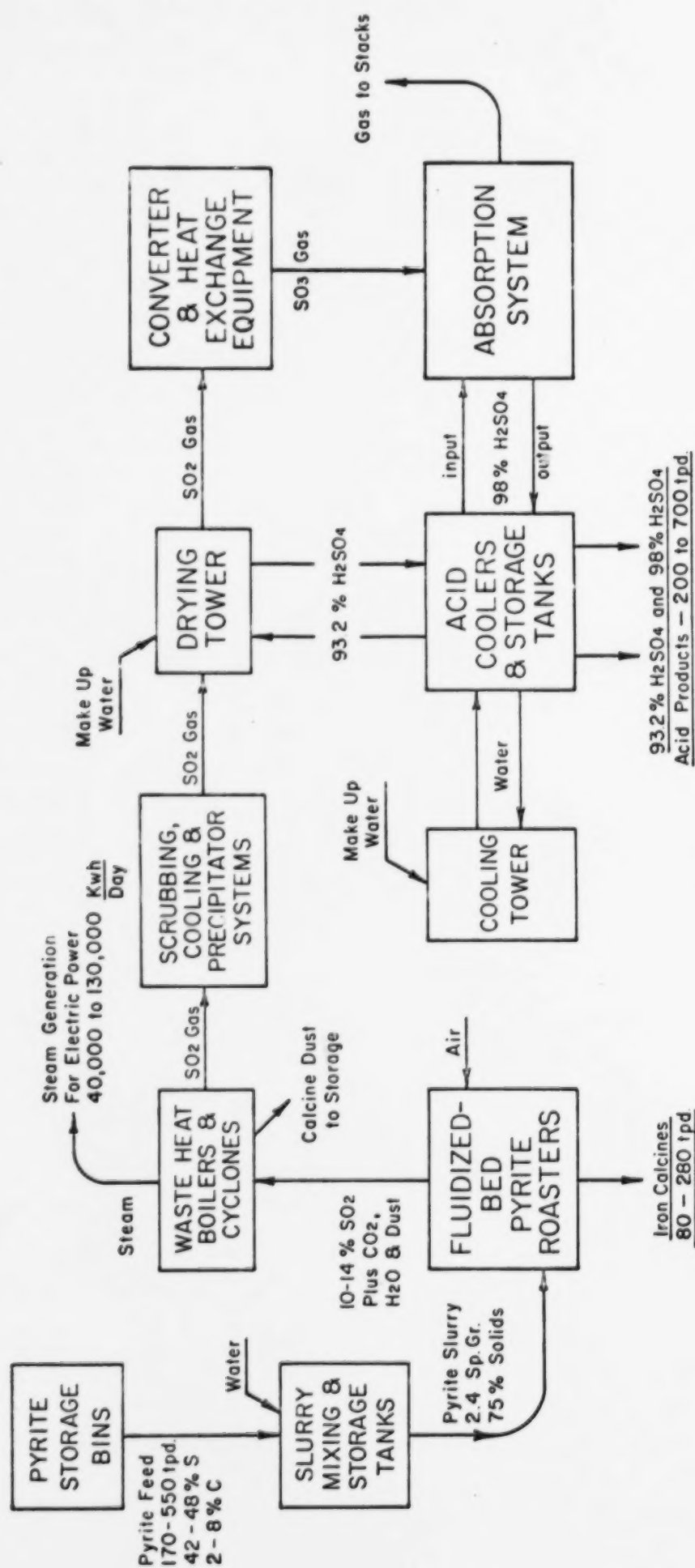
The 6 mesh or 30 mesh x 0 pyrite is fed to the slurry mixing tanks at the required rate to maintain a slurry of approximately 75 percent solids at 2.4 specific gravity. The prepared pyrite slurry is then pumped with slurry pumps to agitating type storage tanks. This arrangement will allow the preparation and storage of sufficient slurry in one shift to feed the roasters for 24 hours and thus simplify labor requirements.

Pyrite slurry is pumped, as needed, from the storage tanks to constant head tanks which insure uniform rates of introduction into the fluidized-bed roasters.

Dead roasting conditions will be maintained in the roasters to provide maximum SO₂ yields and iron calcines with minimum sulfur contents. Eighteen to 25 foot diameter fluidized-bed reactors in banks of two or three units should adequately handle the indicated feed. Air in quantities of 4,600 to 6,000 c.f.m. will be supplied by high pressure blowers to each unit.

Slurry and cooling water will be introduced through the top of the roaster rather than by injection through the side as this has proven to

Figure 3



SIMPLIFIED FLOW SHEET OF CONTACT SULFURIC ACID PLANT UTILIZING COAL PYRITES

Figure 3

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

be effective in reducing dead spots in the fluidized bed. Roasting temperatures will be maintained at 800 to 900 degrees Centigrade.

Liberated sulfur dioxide gas plus carbon dioxide, moisture and calcine dust will flow to waste heat boilers and then high temperature cyclones. Waste heat boilers will be used only when it is desired to utilize the waste heat to provide steam generation as might be the case when the operation is situated in connection with an electric power plant.

If waste heat utilization is not applied, the sulfur dioxide with its contaminants can be directly introduced to the high temperature cyclones for collection of the calcine dust.

The cyclone system will consist of primary and secondary cyclones for each roasting unit. Collected calcines, which can amount to up to 50 percent of the total calcines produced, will supplement the iron calcines that are discharged directly from the fluidized bed. The collected calcines then can be discarded, sintered and stored or converted by magnetic reduction and pelletized as illustrated by Figure No. 4, already described in Section 5.5 of the main report.

The hot sulfur dioxide gas from the cyclones is then processed through the scrubbing, cooling and precipitator systems to purify the gas and remove any remaining dust. From this point the cool sulfur dioxide is passed through a drying tower utilizing 93.2 percent sulfuric acid to remove moisture from the gas by absorption before introduction to the converter and heat exchange equipment.

Heat exchangers are used to reheat the sulfur dioxide gas to 427 to 443 degrees Centigrade for introduction into the converter system and maintain the heat balances necessary.

The dry and purified sulfur dioxide is then passed through the converter where catalytic oxidation occurs with vanadium pentoxide or platinum catalysts to produce sulfur trioxide.

The sulfur trioxide gas in concentrations from 8 to 11 percent is then passed through the absorption system where it produces sulfuric acid by direct absorption with concentrated 98 percent acid supplied from the acid cooling and storage systems.

Acid from the absorption system is cooled and transferred to 98 and 93.2 percent acid storage tanks. Mixing systems are provided between these storage tanks to allow dilution and concentration of products, as required. Acid products are drawn from the storage tanks as required for return to the drying tower and absorption system.

Figure No. 4
SUGGESTED FLOW SHEET
FOR MAGNETIC REDUCTION OF IRON CALCINES
FROM FLUIDIZED-BED PYRITE ROASTERS

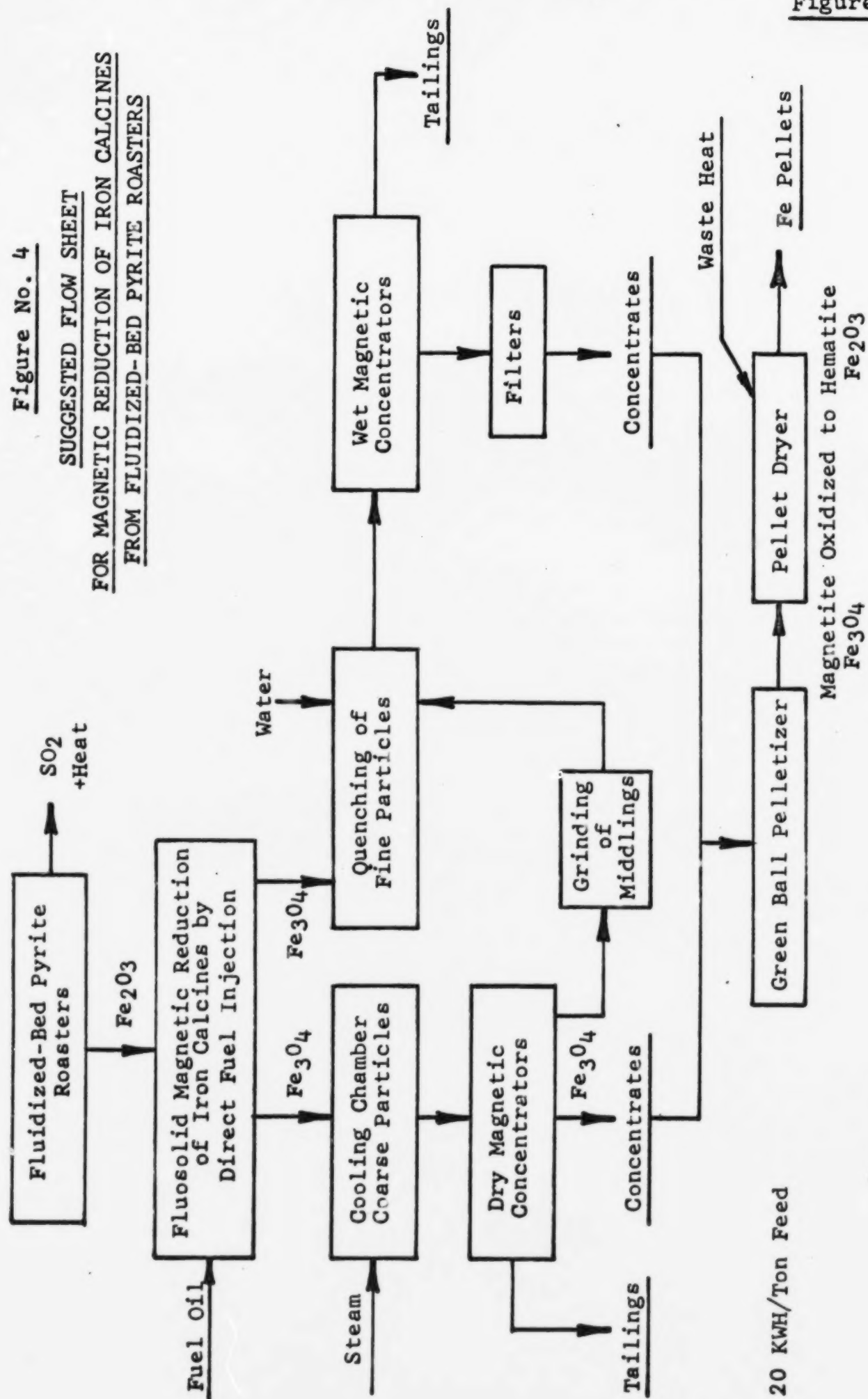


Figure No. 4

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

Large amounts of cooling water (up to 40,000 gallons per ton of acid product in some cases) are required to support the acid cooling system^{11/}. In locations where water supply might be a problem, the utilization of a cooling tower would be necessary to cut water requirements.

As stated previously, iron calcines from the roasters can be sintered or converted by magnetic reduction where markets exist for a high grade iron product in the amounts produced by this system. It should be noted that the flow sheet shown as Figure No. 4 includes wet and dry magnetic concentrating circuits for the purpose of removing excessive gangue material. If the calcines resulting from the roasting of the beneficiated pyrites are low in gangue material, all or part of these concentrating circuits may be eliminated, thus simplifying the magnetic conversion process.

In situations where purity and iron content are high enough, the calcines may be sintered and shipped to appropriate users, thus eliminating the need for magnetic reduction.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

SECTION 4.0 Economics

Capital investment costs, manufacturing costs and estimated profits have been calculated for the proposed contact acid plants utilizing coal pyrites, and they have been tabulated in this section. These costs vary considerably with the capacity of the plants. Therefore, the amount of pyrite available from the coal preparation plant, or plants, is quite important. In an effort to provide comprehensive data, costs have been calculated for sulfuric acid plants producing 200, 450 and 700 short tons per day.

To provide a means of estimating benefits coal operators can expect from the operation of these systems, credits for the various products have been computed based on a production of 10,000 tons per day of clean coal (Plan A) (see Exhibit "A"), for a high sulfur coal with actual pyrite recovered based upon three production rates.

Capital investment costs, as shown in Table No. 3, are based on an estimated fixed capital cost of approximately \$41.50 per ton of acid product per year, or an investment of \$14,400 per ton per daily capacity for the 200 t.p.d. acid plant 11,19/. Current plant and equipment indices have been utilized to up-date all costs and a 6/10 exponential factor has been applied to compensate for the increased capacities of the 450 and 700 t.p.d. plants.

Total fixed capital for the 200, 450 and 700 t.p.d. acid plants is \$2,880,000; \$4,268,000 and \$6,090,000, respectively. The estimated breakdown of these costs is indicated in Table No. 3. Also, a basic processing equipment list is shown in Table No. 3A.

Capital investment figures for the preparation plant pyrite beneficiation circuit have not been included due to the varied beneficiation requirements and would have to be calculated for each individual case. A possible capital investment cost for this circuit may vary from \$150,000 to \$200,000, and would be included in the coal preparation plant design. In some situations it may be possible to recover concentrated pyrite with little or no capital costs.

The estimated manufacturing costs for the acid plants are shown in Table No. 4 and are calculated per short ton of 100 percent sulfuric acid. Total cost per ton of acid for a 200, 450 and 700 t.p.d. plant is \$14.58, \$9.92 and \$8.42, respectively. These costs are based on an annual acid production of approximately 69,500, 156,000 and 240,000 tons.

Table No. 5 indicates the estimated acid profits and credits. Shipping and distribution costs are based on a 300 mile radius at \$9.00 per short ton of acid. It is assumed that the acid will be shipped directly

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

to contract buyers or to acid distribution points for sale at prevailing market prices.

Considering current market prices, the profit per ton of 100 percent acid will range from \$4.07 to \$10.23 for midwest producers and \$3.17 to \$9.33 for eastern producers, depending on the size of the acid plant operated. Acid credits per ton of clean coal will vary from \$0.08 to \$0.72 in the midwest and \$0.06 to \$0.65 in the east, the larger the plant, of course, the more profitable.

Iron calcines, by-products from the pyrite roasters, will be available in amounts from 80 t.p.d. for the 200 t.p.d. acid plant to 280 t.p.d. for the 700 t.p.d. acid plant. Table No. 6 gives estimated sintering costs, profits and iron credits that can be expected when adequate markets allow the utilization of these products 11,20/.

Capital investment for the sintering system will vary considerably with the amount of preparation necessary for the feed, and would have to be calculated for each specific case.

Profit per short ton of calcine or sinter will vary from \$4.00 to \$5.75. Iron credits per ton of clean coal will run from \$0.03 to \$0.16. On the basis of these figures, it is apparent that while sintering would be feasible in connection with the 450 and 700 t.p.d. acid plant, the calcines produced by the 200 t.p.d. acid plant may not warrant sintering. As noted in Table No. 6, the iron credit for the 200 t.p.d. acid plant is based on only \$4.00 credit per ton of untreated calcines 11/.

Table No. 7 summarizes acid and iron credits and indicates the adjusted costs per ton of clean coal (Plan A) when these credits are applied. Before the application of credits, the cost per ton of clean coal obtained from the main report (Table No. 22) is given as \$3.63. Depending on location and size of the acid plants, total acid and iron credits are estimated to run from \$0.10 to \$0.81 per ton of clean coal for a 10,000 t.p.d. preparation plant.

Energy credits, in the form of high pressure steam, are considered as a supplementary credit and are illustrated in Table No. 8. In cases where waste heat can be utilized, up to 235 KWH of electric power can be generated for each ton of roasted pyrite. This could be applicable in cases where the preparation plant is built in conjunction with a power plant and could result in an additional credit of up to \$0.09 per ton of clean coal (Plan A). Also, if magnetic reduction of calcines is practiced, important consideration should be given to the utilization of waste heat systems as a means of reducing fuel costs of the magnetic conversion process.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

It should also be pointed out that in the retreatment of coal preparation plant refuse for acid grade pyrite, some coal recovery would be expected. Credits for this possible recovery are not used, however, in these calculations due to the variable nature of each situation.

Table No. 3

Estimated Capital Investment for Contact Sulfuric
Acid Plants Utilizing Coal Pyrites

Cost Items	<u>Acid Plant Capacity-Short Tons Per Day</u>		
	<u>200</u>	<u>450</u>	<u>700</u>
Purchased Equipment (approx. 25% of Fixed Capital)	\$ 665,000	\$1,080,000	\$1,410,000
Equipment Installation (50% of Pur. Equip. Cost)	332,000	540,000	710,000
Piping (38%)	254,000	410,000	540,000
Instrumentation (33%)	220,000	356,000	465,000
Insulation (8%)	54,000	86,000	115,000
Buildings (10%)	66,000	108,000	140,000
Land and Improvements (9.5%)	63,000	103,000	130,000
Utilities (15%)	<u>100,000</u>	<u>162,000</u>	<u>210,000</u>
<u>PHYSICAL PLANT COST</u>	\$1,920,000	\$2,845,000	\$4,070,000
Erection	480,000	711,000	1,000,000
Engineering Fee	240,000	356,000	510,000
Contingency (12.5%)	<u>240,000</u>	<u>356,000</u>	<u>510,000</u>
TOTAL FIXED CAPITAL	\$2,880,000	\$4,268,000	\$6,090,000

Table No. 3-A (Supplement)

Processing Equipment

1. Pyrite Storage
 - a. Bins
 - b. Vibratory Feeders
 - c. Conveyors
2. Slurry Mixing & Storage
 - a. Screw Conveyors
 - b. Agitation Type Storage Tanks
 - c. Constant Head Feed Tanks
 - d. Slurry Pumps
3. Fluidized-Bed Roasters & Blowers
4. Waste Heat Boilers & Cyclones
5. Purification Equipment
 - a. Scrubber & Stripper
 - b. Electrostatic Mist Precipitator
6. Drying Tower
7. Converter & Heat Exchange Equipment
8. Absorption Tower
9. Acid Coolers & Storage Tanks
10. Water Cooling Tower

Table No. 4

Estimated Manufacturing Costs for Contact
Sulfuric Acid Plants Utilizing Coal Pyrites

Cost Per Short Ton 100% H₂SO₄

	<u>Acid Plant Capacity-Short Tons Per Day</u>		
	<u>200</u>	<u>450</u>	<u>700</u>
Raw Materials (Beneficiated Pyrite)	\$ 0.275	\$ 0.250	\$ 0.225
Labor (0.48, 0.30 & 0.20 Man hrs/ton acid)	2.256	1.410	0.940
Supervision (25% of Labor)	0.564	0.353	0.235
Maintenance (6% Fixed Capital/yr.)	2.486	1.642	1.504
Plant Supplies (10% of Maintenance)	0.250	0.164	0.151
Utilities (120, 110 & 100 kwh respectively)	<u>1.200</u>	<u>1.100</u>	<u>1.000</u>
<u>DIRECT MANUFACTURING COST</u>	\$ 7.029	\$ 4.919	\$ 4.055
Payroll Overhead (20% of Labor)	\$ 0.451	\$ 0.282	\$ 0.188
Laboratory (5% of Labor)	0.113	0.071	0.047
Plant Overhead (10% of Labor)	<u>0.226</u>	<u>0.141</u>	<u>0.094</u>
<u>INDIRECT MANUFACTURING COST</u>	\$ 0.790	\$ 0.494	\$ 0.329
Depreciation (10% of Fixed Capital/yr.)	\$ 4.144	\$ 2.736	\$ 2.506
Property Taxes (1% of Fixed Capital/yr.)	0.414	0.274	0.251
Insurance (1%)	<u>0.414</u>	<u>0.274</u>	<u>0.251</u>
<u>FIXED MANUFACTURING COST</u>	\$ 4.972	\$ 3.284	\$ 3.008
<u>TOTAL MANUFACTURING COST</u>	<u>\$12.791</u>	<u>\$ 8.697</u>	<u>\$ 7.384</u>
General Expenses (14% of Mfg. Cost) (Admin. & Sales Cost)	<u>\$ 1.791</u>	<u>\$ 1.218</u>	<u>\$ 1.034</u>
<u>TOTAL COST</u>	\$14.582	\$ 9.915	\$ 8.418

Table No. 5

Estimated Sulfuric Acid Credits, Per Short Ton of Clean CoalFrom Plan A - 10,000 t.p.d. Clean Coal

<u>Acid Plant Capacity</u>	<u>200 Ton Per Day</u>		<u>450 Ton Per Day</u>		<u>700 Ton Per Day</u>	
	<u>Midwest</u>	<u>Eastern</u>	<u>Midwest</u>	<u>Eastern</u>	<u>Midwest</u>	<u>Eastern</u>
Base Price of 100% H ₂ SO ₄ per short ton (f.o.b. Distr.pt.)	\$27.650	\$26.750	\$27.650	\$26.750	\$27.650	\$26.750
Cost of Acid Product per short ton	\$14.582	\$14.582	\$ 9.915	\$ 9.915	\$ 8.418	\$ 8.418
300 Mile Shipping & Distr. Costs	<u>9.000</u>	<u>9.000</u>	<u>9.000</u>	<u>9.000</u>	<u>9.000</u>	<u>9.000</u>
Delivered Cost of Acid	\$23.582	\$23.582	\$18.915	\$18.915	\$17.418	\$17.418
Profit Per ton of Acid (before taxes)	\$ 4.068	\$ 3.168	\$ 8.735	\$ 7.835	\$10.232	\$ 9.332
Acid Credit per Short Ton of Clean Coal	\$ 0.081	\$ 0.063	\$ 0.393	\$ 0.353	\$ 0.716	\$ 0.653

Table No. 6

Estimated Iron Calcine or Sinter Credits Per Short
Ton of Clean Coal Based on
10,000 t.p.d. Clean Coal (Plan A)

	<u>Acid Plant Capacity-Short Tons Per Day</u>		
	<u>200</u>	<u>450</u>	<u>700</u>
<u>Iron Calcine Production:</u>			
Short Tons Per Day	80	180	280
Short Tons Per Year	27,760	62,460	97,160
<u>Cost Items:</u>			
Sintering Per Short Ton	-	\$ 2.40	\$ 2.00
Handling	-	0.15	0.15
Expenses	-	0.25	0.20
Total Sintering Cost	-	\$ 2.80	\$ 2.35
Shipping (300 mi. by rail)@ 1.3¢ per ton mile	-	3.90	3.90
Delivered Cost of Sinter		\$ 6.70	\$ 6.25
Selling Price of Sinter	-	\$12.00(a)	\$12.00(a)
Profit Per Short Ton of Sinter (Before Taxes)	\$4.00(b)	\$ 5.30	\$ 5.75
Calcine or Sinter Credit	\$0.032	\$0.095	\$0.161

Notes: (a) Estimated at a current market value of approximately \$13.50 per long ton delivered with an average iron content of 60%.

(b) Based on a straight iron calcine credit.¹¹ Calcine production of the 200 t.p.d. acid plant would not warrant capital investment for a sintering plant.

Table No. 7

Summary of Acid and Iron Credits and Adjusted Cost Per Short Ton of Clean Coal

Based on Production of 10,000 t.p.d. Clean Coal (Plan A)

<u>Acid Plant Capacity</u>	<u>200 Short Tons/Day</u>		<u>450 Short Tons/Day</u>		<u>700 Short Tons/Day</u>	
	<u>Location</u>		<u>Location</u>		<u>Location</u>	
	<u>Midwest</u>	<u>Eastern</u>	<u>Midwest</u>	<u>Eastern</u>	<u>Midwest</u>	<u>Eastern</u>
Acid Credit	\$0.081	\$0.063	\$0.393	\$0.353	\$0.716	\$0.653
Iron Credit	<u>0.032</u>	<u>0.032</u>	<u>0.095</u>	<u>0.095</u>	<u>0.161</u>	<u>0.161</u>
Total Credits	\$0.113	\$0.095	\$0.488	\$0.448	\$0.877	\$0.814
Cost Clean Coal (before credits)	\$3.628	\$3.628	\$3.628	\$3.628	\$3.628	\$3.628
<u>Adjusted Costs Clean Coal</u>						
With acid credit only	\$3.547	\$3.565	\$3.235	\$3.275	\$2.912	\$2.975
With acid and iron credit	\$3.515	\$3.533	\$3.140	\$3.180	\$2.751	\$2.814

Table No. 8

Supplementary Credits

Energy Credits:

High pressure steam recovered from waste heat boilers will produce approximately 235 KWH of generated power per ton of roasted pyrite feed. At an estimated value of \$0.007 per KWH, a credit of \$1.64 per ton of pyrite feed can be realized in cases where this energy can be utilized.

Based on a coal production of 10,000 t.p.d., energy credits per ton of clean coal can be summarized as follows:

	<u>Acid Plant Capacity-Short Tons Per Day</u>		
	<u>200</u>	<u>450</u>	<u>700</u>
Pyrite Feed-Short Tons/Day	170	360	550
Generated Power Potential- KWH/day	40,000	84,600	130,000
Energy Credit Per Short Ton Clean Coal	\$0.028	\$0.043	\$0.091

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE

CHICAGO, ILLINOIS 60606

SECTION 5.0 References

1. Burke, S.P., and Downs, R., "Oxidation of Pyritic Sulfur in Coal Mines". Transactions of the American Institute of Mining Engineers, Vol. 130, 1938, p. 425.
2. Mitchell, D.R., "The Recovery of Pyrite from Coal Mine Refuse". Transactions of the American Institute of Mining Engineers, Vol. 157, 1944, pp. 141-146.
3. Spencer, K.A., "Pyrite Recovery from Coal Mine Refuse". American Mining Congress Yearbook, 1940, pp. 97-102.
4. Yancey, H.F., "Some Chemical Data on Coal Pyrite". Chemical and Metallurgical Engineering, Vol. 22, No. 3, January 21, 1920, pp. 105-109.
5. Holbrook, E.A., "The Utilization of Pyrite Occurring in Illinois Bituminous Coal". University of Illinois Bulletin, No. 51, Vol. 14, August 20, 1917.
6. Mitchell, D.R., "Reclamation of Refuse in Illinois Coal Mines". Illinois State Geological Survey, Circular No. 23, 1938.
7. Davis, S.H., "Commercial Recovery of Pyrite from Coal"., Transactions of the American Institute of Mining Engineers, Vol. 63, 1920, p. 637.
8. Levitsky, Serge L., "Sulfur". American Mining Congress Journal, Vol. 52, February, 1966.
9. Ambrose, P.M., "Sulfur and Pyrites". Mineral Facts and Problems, Bulletin 630, U.S. Bureau of Mines, 1965 Edition.
10. Ross, H.V., "Roasting in the Iron and Steel Industry". Canadian Mining Journal Transactions, Volume LXIV, 1961, pp. 345-350.
11. Thompson, R.B. and Jukkola, W.W., "Manufacture of Sulfuric Acid". ACS Monograph No. 144, Reinhold Publishing Corp., 1959.
12. Schneider, Ben, "Multiple Hearth Roasting of Sulfides in the Zinc Roasting Plant of the Hudson Bay Mining & Smelting Co., Ltd., Flin Flon, Manitoba". The Canadian Mining and Metallurgical Bulletin, Vol. 54, No. 592, August, 1961, p. 585.
13. Eyre, R.E., "Suspension Roasting of Zinc Concentrate at Trail, British Columbia". The Canadian Mining and Metallurgical Bulletin, Vol. 54, No. 592, August, 1961, p. 589.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

14. Stollery, J.L., "Fundamentals of Fluid Bed Roasting of Sulfides". Engineering and Mining Journal, Vol. 165, No. 10, October, 1964, p. 96.
15. Anonymous., "First Commercial Magnetic Roasting Plant Utilizes Fluid Bed Reactors". Engineering and Mining Journal, Vol. 165, No. 11, November, 1964, p. 104.
16. Colombo, U. and others, "Montecatini's Revamped Pyrite Flow Sheet Overcomes the Heat-Iron-Sulfur Snags". Engineering and Mining Journal, Vol. 166, No. 4, April, 1965, p. 94.
17. Guccione, E., "Fluidization Turns Pyrites into High-Grade Iron Ore". Chemical Engineering, May 10, 1965.
18. Scharf, H.B., and Dominguez, E.C., "The Fluidized Bed Reactor Installation at Sparrows Point". Transactions of the American Institute of Mining Engineers, Vol. 205, 1956, also Mining Engineering, May, 1956, p. 518.
19. Aries, R.S., and Newton, R.D., "Chemical Engineering Cost Estimation". McGraw-Hill Book Company, New York, 1955.
20. Roe, L.A., "Iron Ore Beneficiation". Mineral Publishing Company, Lake Bluff, Illinois, 1957.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

SECTION 6.0 Supplementary References

- Thompson and Roesner, "Fluid-Bed Roasting Principles and Practice". American Institute of Mining Engineers Symposium, New York, 1960.
- Peters, E., "Roasting Rates and Elementary Mechanisms". The Canadian Mining and Metallurgical Bulletin, Vol. 54, No. 592, August, 1961, p. 580.
- Kellog, H., "Equilibrium Consideration in the Roasting of Metallic Sulfides". Transactions of the American Institute of Mining Engineers, Vol. 206, 1956.
- Fisher, "Some Applications of Physical Chemistry to the Sulfate Roasting of Metallic Sulfides". Transactions of the Institute of Mining and Metallurgy, London, Vol. 73, 1963-1964, pp. 109-176.
- Max, Leva., "Fluidization". McGraw-Hill Publishing Company, New York, 1960.
- Zenz and Othmer, "Fluidization and Fluid Particle Systems". Reinhold Publishing Company, New York, 1960.
- Cavanagh and Last, "Experimental and Commercial Magnetic Roasting". The Canadian Mining and Metallurgical Bulletin, Vol. 54, No. 592, August, 1961, p. 615.
- Wasson, P.A., "Experimental Conversion of Hematite to Magnetite". U.S. Bureau of Mines, Reports of Investigations No. 6338, 1963.
- Thornhill, P.G., "The Falconbridge Iron Ore Process". The Canadian Mining and Metallurgical Bulletin, Vol. 54, No. 592, August, 1961, p. 601.
- Kurushima, H., and Foley, R.M., "Fluosolids Roasting of Dow's Yanahra Sulfides". Mining Engineering, October, 1958, p. 1057.
- Anonymous., "Brunswick Mining's Huge Complex to Rely on World-Wide Technology". Engineering and Mining Journal, Vol. 166, No. 12, December, 1965, p. 70.
- Dennis, W.H., "Metallurgy of the Non-Ferrous Metals". Pitman Publishing Company, New York, 1961, pp. 155-159.
- Kirkaldy, J.S., and Ward, R.G., "Aspects of Modern Ferrous Metallurgy". University of Toronto Press, 1964, pp. 45-65.
- Stewart, A., and Work, H.K., "R-N Direct Reduction Process". Journal of Metals, July, 1958, p. 460.

PAUL WEIR COMPANY

20 NORTH WACKER DRIVE
CHICAGO, ILLINOIS 60606

Whitehead, A.B., and Vrie, R.W., "Fluidized Bed Roasting of Copper Concentrates". Proceedings of the Australian Institute of Mining and Metallurgy, Vol. 199, p. 51, 1961.

Shibler, B.K., and Hovey, M.W., "Processes for Recovering Sulfur from Secondary Source Materials". U.S. Bureau of Mines, Information Circular No. 8076, 1962.

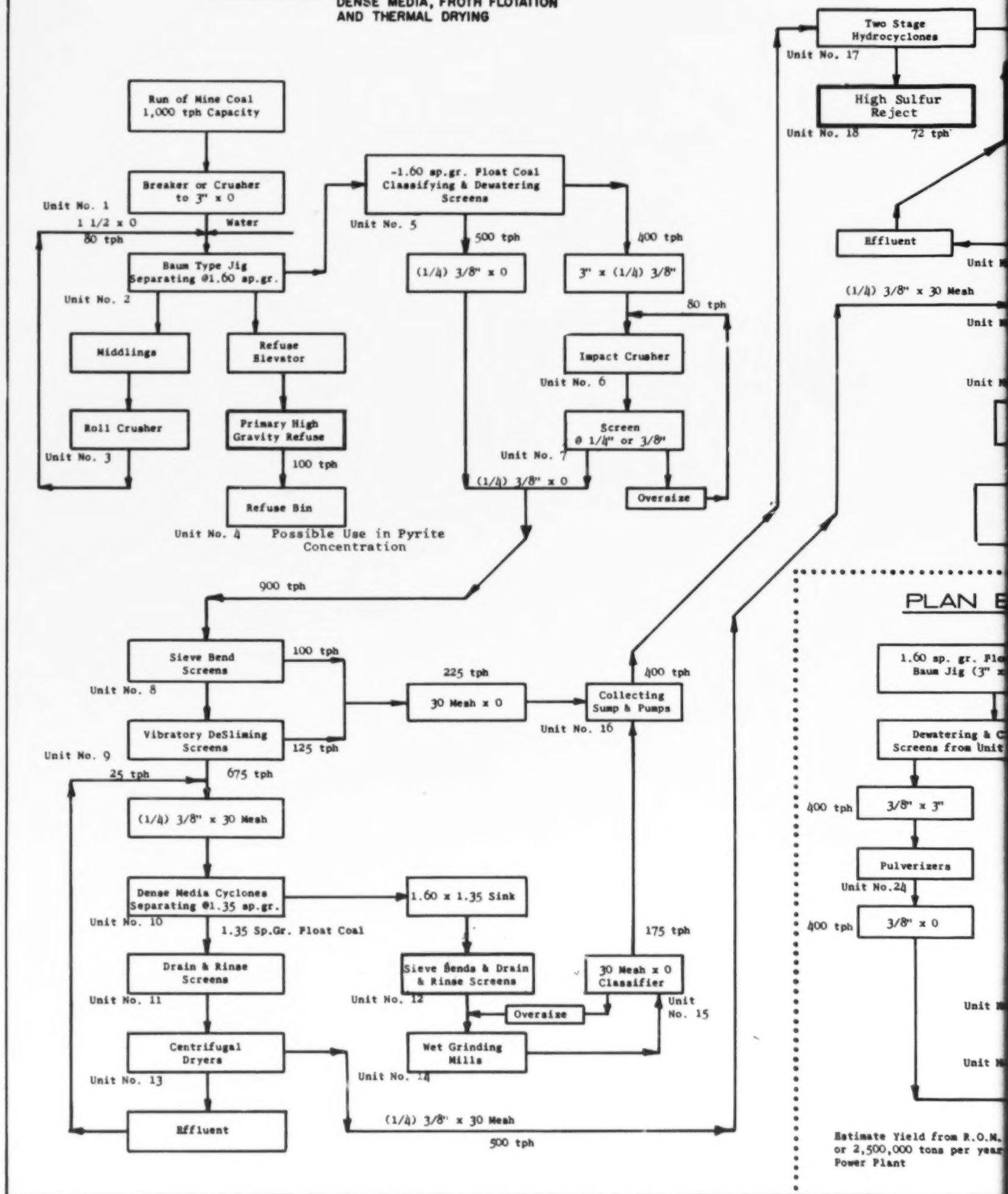
Dailey, Jr., W.W., and Bunge, F.H., "Reaction of Low-Grade Non-Magnetic Iron Ores to Magnetic Roasting in a Fixed Bed". Transactions of the American Institute of Mining Engineers, Vol. 217, 1960, p. 154.

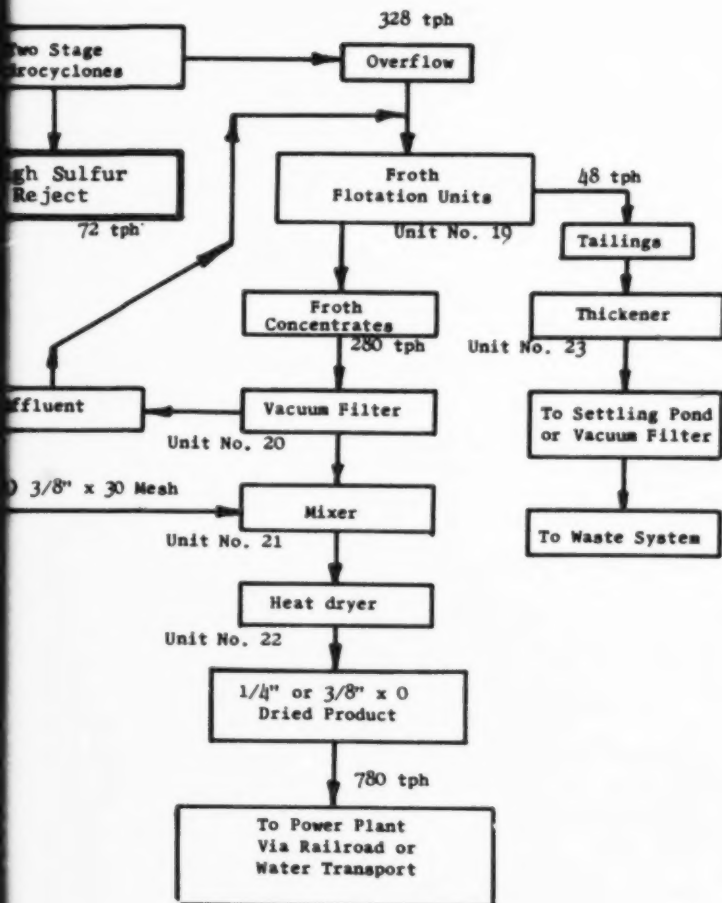
Pearce, M.O., "Low Intensity Dry Magnetic Concentration". The Canadian Mining and Metallurgical Bulletin, Vol. 155, No. 604, August, 1962, p. 571.

Ronolinna, U., "Dry Magnetic Separation of Finely Ground Magnetite in a Rotating Magnetic Field". Acta Polytechnica Scandinavica, (Acta, 1961), p. 303.

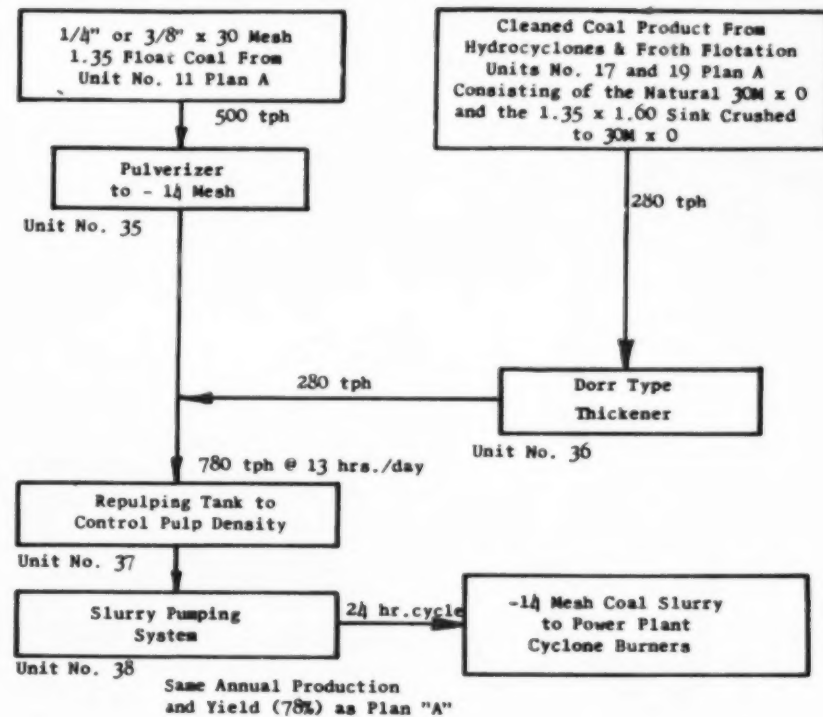
Dalmav Gimenez, F., "Study on Heat Recovery in Pyrite Roasting". Genie Chim., 89 (4), 111-117, (April, 1963) Fuels Abstract No. 3727, (in French).

PLAN A: 3/8x0 PRODUCT USING JIGS, DENSE MEDIA, FROTH FLOTATION AND THERMAL DRYING





PLAN C: PLAN "A" PROCESSING, WITHOUT THERMAL DRYING, TO PRODUCE -14 MESH COAL SLURRY



PLAN B: USING PLAN "A" JIG PLANT WITH FINAL SULFUR REDUCTION AT POWER PLANT

